GROWTH AND CHARACTERIZATION OF A SINGLE CRYSTAL CVD DIAMOND NUCLEAR DETECTOR

A. Balducci, Marco Marinelli, E. Milani, M.E. Morgada, G. Pucella, A. Tucciarone, G. Verona-Rinati

Dipartimento di Ingegneria Meccanica, Università di Roma "Tor Vergata", Via del Politecnico 1, I-00133 Roma, Italy

M. Angelone, M. Pillon

Associazione EURATOM-ENEA sulla Fusione, Via E. Fermi 27, I-00044 Frascati (Roma), Italy

R. Potenza, C. Tuvè

INFN – Dipartimento di Fisica, Università di Catania, Italy

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Abstract

The deposition conditions and the detection properties of a homoepitaxial diamond film, grown by microwave Chemical Vapor Deposition (CVD) on a HPHT single crystal substrate are reported. The charge collection spectrum measured under irradiation with a triple ^{239}Pu ^{241}Am ^{244}Cm source, emitting 5.16 MeV, 5.48 MeV and 5.80 MeV α-particles respectively shows three clearly resolved peaks, with an energy resolution of about 1.1%. Both the charge collection efficiency and the energy resolution reach saturation values when the applied voltage exceeds 60 V, suggesting 100% collection efficiency. The detector was also tested with 14.8 MeV neutrons. The obtained collection spectrum shows a well separated $^{12}C(n,\alpha_0)^9Be$ reaction peak.

RESULTS

Diamond is known to be a suitable material for radiation detectors to be used in harsh environments. Since detector grade natural diamonds are extremely rare and expensive, and HPHT crystals contain too many defects to be used as radiation detectors, the most widely used technique to produce such devices is Chemical Vapor Deposition (CVD). However the polycrystalline nature of heteroepitaxial CVD samples severely limits the device performance, in particular energy resolution. A great effort is therefore now being devoted to the realization of homoepitaxial CVD diamond detectors. A resolution as low as 0.4% and 2.9% was reported as the best results obtained for α-particle and for neutron detection respectively[1,2], but a degradation of the device performance was observed during long time particle irradiation, due to polarization effects[2]. Moreover, the samples used are of industrial origin, so that the growth conditions are not known.

We report on the growth conditions and the α-particle and neutron detection properties of a homoepitaxial diamond film deposited by CVD in Roma "Tor Vergata" University laboratories. The film was deposited in a microwave plasma CVD tubular reactor on a low cost (100) HPHT single crystal substrate 4.0x4.0x0.3 mm^3 in size. The CVD diamond layer was deposited for 92 h, at 700 °C, in a 1% CH_4/H_2 mixture and is 110 μm thick (1.2 μm/h growth rate). Metallic contacts 2 mm in diameter and 100 nm thick were evaporated on the film in a sandwich geometry, without removing the HPHT 315 μm thick substrate. The device was connected through an Ortec 142 A charge preamplifier to a 6 μs shaping amplifier and a multichannel analyzer.

In Fig. 1 the response of the detector to irradiation from a triple ^{239}Pu ^{241}Am ^{244}Cm source, emitting 5.16 MeV, 5.48 MeV and 5.80 MeV α-particles is reported at 80 V bias voltage. A high signal to noise ratio and a very good energy resolution is observed, as shown by the clear separation of the peaks of the triple α source. The 1.1% resolution of the diamond detector is to be compared with the 0.4% value of a calibrated Si detector. Very poor detection efficiency is observed when irradiating from the substrate side, ruling out the substrate as the source of the signal. The energy resolution and the normalized charge collection efficiency were measured as a function of the applied voltage. A saturation value is reached in both cases for bias voltages exceeding +60 V. This suggests that approximately a 100% collection efficiency is achieved from the CVD diamond film, i.e. all the charges generated in the deposited layer can reach the substrate. Good stability was observed under a 4 particles/s·mm^2 α-particle flux, without any detectable polarization effect for irradiation time of the order of 1 hour.

Irradiation with 14.8 MeV neutrons was also performed using a T(d,n)^{4}He source. The diamond detector was simultaneously irradiating by an ^{241}Am α source positioned in air 4.2 mm away from the sample surface. In such a way, see Fig. 2, the α particle peak is superimposed to the neutron spectrum, allowing its energy calibration. Due to the 4.2 mm air absorbing layer, the energy of the α particles impinging on thje detector is 5.1 MeV as calculated by SRIM simulation. The measured spectrum (Fig. 2) is consistent with those reported in literature, with the ^{12}C(n,α$_0$)^{9}Be reaction peak well separated from the ^{12}C(n,n')3α shoulder. The FWHM of the 9.1 MeV ^{12}C(n,α$_0$)^{9}Be peak is about 0.5 MeV, which is thought to be compatible with the energy spread of the incident neutron. Such a value favorably compares with the values reported in literature[2], especially if the much broader neutron energy spread of the 0° detector angular position with respect to the deuteron beam is taken into account.

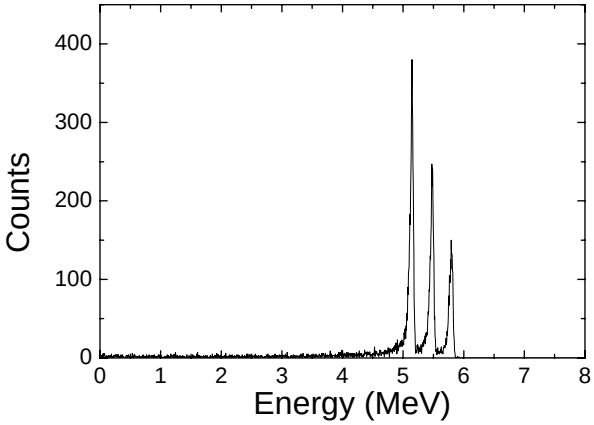

Figure 1: Detector response obtained from the triple ^{239}Pu ^{241}Am ^{244}Cm α source

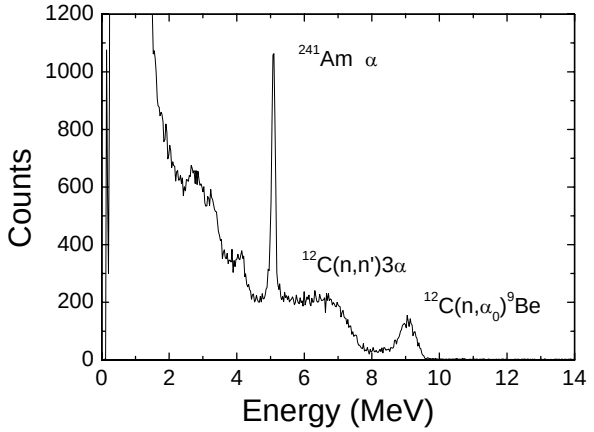

Figure 2: Neutron spectrum obtained with 14.8 MeV neutrons and ^{241}Am α-particles.

References

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